CHAPTER 4 -- METHODS FOR DEVELOPING MINIMUM FLOW CRITERIA

METHODS CONSIDERED TO DEVELOP MFL CRITERIA

River management is a complex process that requires consideration of a number of variables. Minimum flows are an important component of riverine flow characteristics. However, providing a minimum flow represents only one aspect of management and/or restoration of river hydrology. Focusing on a single aspect of river hydrology (minimum flows) is an overly simplistic treatment of complex ecosystem interactions. Long-term hydrological data, especially measures of variability, have been under utilized in most management decisions aimed at river ecosystem protection or restoration (National Research Council 1992).

Because of the intrinsic ecological complexity of estuaries, scientists and managers have also objected to the idea that minimum flows can be set for estuaries. Complexity in itself, however, is not a sufficient reason to question the concept of minimum flows for estuaries. In fact, it simply supports the fact that complex biological systems, such as those in estuaries, require more study. Due to the lack of understanding and a shortage of previous attempts to establish minimum flows, estuarine scientists and managers do not have even simplistic minimum flow examples to study or criticize. Rather than waiting until all information is available before making a management decision, the best approach is adaptive: set inflows based on assumptions derived from conceptual and mathematical modeling using best available information, monitor the results for success or failure, continue research, and reevaluate flow targets.

Appendix R includes a brief review of a number of possible approaches that were considered in the development of Minimum Flow and Level Criteria for the Loxahatchee River. Based on this assessment, it was determined that a combination of approaches would provide the best results to most effectively apply the available information.

1. Estimation of Historical Flow Conditions. Because of a general lack of historical flow and salinity data for the Loxahatchee River and Estuary, a hydrological modeling approach was developed to represent historical water levels and flow patterns. This effort is partly complete, but needs to be extended, at a higher spatial and temporal resolution, to provide more detailed analyses. An effort was also made to predict historical (pre-development) flows from the Loxahatchee River watershed based on current rainfall patterns (1965-1995), historical land cover, climate, topographic, and water level data. Preliminary results of this analysis are provided in **Appendix N**

2. Estimation of Current Hydrologic Conditions, Groundwater-Surface Water Interactions and Water Budget. A modeling approach was also developed to develop an interactive groundwater-surface water model for the portion of the watershed that lies within northern Palm Beach County. Preliminary results of this analysis are provided in **Appendix I.**

3. Instream Flows. The effects of existing inflows to the river from different surface water sources and groundwater on salinity in the river were initially estimated based on statistical relationships between measured flows and measured salinity data. Results of these analyses are provided in **Appendix D**.

4. Hydrologic Variability. The flow and salinity data were later incorporated into a hydrodynamic model of the river and estuary, which was used to generate salinity profiles for the system under different flow conditions. The hydrodynamic model was also used, in combination with historical USGS flow records, to simulate a 30-year salinity record for the period from 1971-2000, at selected sites along the Northwest Fork (**Appendix E**).

5. Habitat Approaches. The historic condition of the freshwater floodplain swamp community (swamp hardwoods and cypress) was documented based on aerial photography (see **Appendix B**). An assessment of the current condition of this community was made by conducting field surveys (**Appendix C**) and the responses of this community to river flow, salinity and soil conditions were determined. (see **Chapter 5**). A river vegetation/salinity model was also developed that could be used as a tool to predict future changes in the floodplain community that may occur in response to changes in river flow and salinity.

6. Indicator Species. Six species of hardwood trees were identified as indicator species of a freshwater swamp community and predominantly freshwater conditions in the floodplain. Distribution of these species along the river was documented and related to river flow, surface water salinity and soil salinity conditions (see **Chapter 5** and **Appendix C**).

7. Valued Ecosystem Component (VEC). The indicator species approach was expanded to include the VEC concept. Management goals were established based on protection of the VEC species, which in this case represents those freshwater plants that are most sensitive to the environmental factor of interest (salinity), as described in **Chapter 5**.

METHODS USED

Establishing Geographic Locations along the River.

During the examination of previous studies of the Loxahatchee River, it was noted that the various researchers used slightly different methods to measure locations along the river. The most common approach was to measure river miles upstream from the Jupiter Inlet along the

main channel of the river. Problems occurred when the channel was altered due to changes in oxbow structure. To resolve this issue, and establish a common measurement scale for SFWMD investigations and future studies of the River, locations along the river were remeasured based on current conditions and Global Positioning System (GPS) readings were taken at each mile marker. These readings were later converted to latitude-longitude coordinates. **Table 15** shows how the mileage locations determined by District staff compare to mileage points used in other investigations and provides the corresponding latitude-longitude coordinates fore these stations.

Table 15. Comparison of SFWMD river mile locations to river mile and station locations identified in research literature (see **Figure 16** for SFWMD station locations).

SFWMD 2001 River Mile**	SFWMD Veg Sites	Lox. River Dist. WQ Sites	Dent 1997; Dent & Ridler 1997	Law Environmental 1991; Mote Marine Lab 1990a *	McPherson & Sabanskas 1980; Russell & McPherson 1984	Long.	Lat.
Loxahatchee River Sites							
0				0		-80.070991516	26.944124222
1				1	0.9	-80.086639404	26.947099686
2				2	1.9	-80.102195740	26.950460434
3				2.8	3	-80.116523743	26.956796646
4				3.9	4	-80.124176025	26.967786789
5	5B			4.9	4.8	-80.139039353	26.982712901
6				6	5.8	-80.142562866	26.985563278
6.3	6A					-80.143669519	26.984342169
6.6		WQ #63	6.5				
6.9	6B					-80.147410631	26.988542914
7				7	6.7	-80.145202637	26.988861084
7.3	7A					-80.147187791	26.990281967
7.5	7B					-80.149975096	26.991066622
7.8		WQ #64	7.3				
7.9	7C					-80.150862762	26.988849080
8				8.4	8.4	-80.153236389	26.989992142
8.1	8A					-80.153982377	26.990833609
8.4	8B					-80.155118577	26.989388511
8.6		WQ #65	8.1				
8.7	8C					-80.157838347	26.989749400
8.9	8st					-80.159289147	26.986940222
9				9.6	9.3	-80.158821106	26.986169815
9.1	9A					-80.159358557	26.985374195
9.2	9B					-80.160870447	26.983861002
9.4		WQ #66					
9.5	9hl					-80.161667250	26.985204790
9.7	9C					-80.163800034	26.982719318
10				10.6	10.8	-80.165061951	26.981418610
10.2	10A					-80.165062424	26.980186754
10.3	10B					-80.164987106	26.978938944
10.6	10C					-80.165192015	26.976525692
10.7		WQ #67					
Kitching Creek Sites							
	A					-80.154898869	26.991771447
	B					-80.155330876	26.992670262
	C					-80.156664449	26.992851025
	D					-80.156095466	26.993647772
	E					-80.155459331	26.994103015
	F					-80.156193578	26.995723248

* Approx. river mile locations based on figures contained in the research literature (specific river mile locations not identified)
**Landmark locations: First Shoal -- 6.8 miles; Second Shoal -- 7.8 miles; Mouth of Kitching Creek -- 8.2 miles

Hydrologic and Hydrodynamic Methods

Review of Historical and Current Conditions

Review of available USGS and SFWMD flow data and stage records was conducted using the District's DBHydro database for the Lainhart Dam, Cypress Creek, Hobe Grove Ditch, and Kitching Creek. Data are provided in **Appendix D. Table 16** is a summary of the flow records obtained from the DBHydro database used in this study. Historical salinity data were also provided by the Loxahatchee Environmental Control District for four sites along the river. These data were reviewed and analyzed to produce descriptive statistics, and trend analyses. Selected data were plotted to generate flow vs probability distributions and time series of flows through structures and tributaries. The long-term flow records and collected salinity database were used as input to a hydrodynamic salinity model developed for the river and estuary (**Appendix E**).

Development of a Hydrodynamic/Salinity Model

A hydrodynamic/salinity model was developed to study the influence of freshwater input on the salinity conditions in the Loxahatchee River and downstream estuary. The purpose of this modeling effort was to predict salinity conditions at various points in the river and downstream estuary with respect of freshwater inflow rates and tidal fluctuations.

Table 16. DBHydro Flow Data Available for the Loxahatchee River and Estuary

Location	Station Name	Alternate station Id	Data Type	Agency	Period of record	Db Keys
Lainhart Dam	LNHRT_W	20641421 60641421	Mean Flow Mean Flow	WMD WMD	1989-1994 1995-2001	JI987 JI988
G-92 structure	G-92_C	20741421 50741421	Mean Flow Mean Flow	WMD WMD	1977-1988 1988-2001	05624 05623
Lainhart Dam (USGS station upstream of Lainhart Dam)	LOX	02277600	Mean Flow **Mean Stage**	USGS USGS	1971-2001 1971-2001	00295 00293
Cypress Creek	LOX.CYPR_O	265816080110000 52040421	Mean Flow Mean Flow	USGS WMD	1980-1982 1984-1991	02968 05442
Hobe Grove Ditch	LOX.HOBE_O	265907080103000 51940421	Mean Flow Mean Flow	USGS WMD	1979-1982 1984-1991	02988 05448
Kitching Creek	KITCHING	270022080094600	Mean Flow	USGS	1979-2000	03006
S-46 structure	S46_S	20341421 50341421	Mean Flow	WMD WMD	1992-2001 1961-1993	15734 04370

<u>Model Description</u>

The software used in the development of Loxahatchee River Hydrodynamics/ Salinity Model were computer programs RMA-2 and RMA-4 that were developed by Army Corps of

Engineers (USACE 1996). RMA-2 is a two dimensional depth averaged finite element hydrodynamic numerical model. It computes water surface elevations and horizontal velocity components for subcritical, free-surface flow in two dimensional flow fields. RMA-2 computes a finite element solution of the Reynolds form of the Navier-Stokes equations for turbulent flows. Friction is calculated with the Manning's or Chezy equation, and eddy viscosity coefficients are used to define turbulence characteristics. Both steady and unsteady state (dynamic) problems can be analyzed. The program has been applied to calculate water levels and flow distribution around islands; flow at bridges having one or more relief openings, in contracting and expanding reaches, into and out of off-channel hydropower plants, at river junctions, and into and out of pumping plant channels; circulation and transport in water bodies with wetlands; and general water levels and flow patterns in rivers, reservoirs, and estuaries.

The water quality model, RMA-4, is designed to simulate the depth-average advection-diffusion process in an aquatic environment. The model is used for investigating the physical processes of migration and mixing of a soluble substance in reservoirs, rivers, bays, estuaries and coastal zones. The model is useful for evaluation of the basic processes or for defining the effectiveness of remedial measures. For complex geometries, the model utilizes the depth-averaged hydrodynamics from RMA-2.

The formulation of RMA-4 is limited to one-dimensional (cross-sectionally averaged) and two-dimensional (depth-averaged) situations in which the concentration is fairly well mixed in the vertical direction. It will not provide accurate concentrations for stratified situations in which the constituent concentration influences the density of the fluid. The preliminary results indicated that the model was able to predict the salinity fluctuation driven by the tide cycle and the influence of freshwater input on the salinity regime in the river.

Modeling Assumptions

Due to a lack of data, various assumptions concerning freshwater inflow were made. First, discharges from Kitching Creek, Hobe Grove Ditch, etc. were calculated as a constant fraction of discharge at Lainhart Dam. Another assumption was a constant input from groundwater of 40 cfs. These assumptions have two important consequences as follows: a) the total inflow to the Northwest Fork associated with a flow of 35 cfs from Lainhart Dam is therefore somewhat larger and includes discharges from groundwater and other tributaries, and b) the flows for the other tributaries were assumed to be proportional to the flows from Lainhart Dam, and hence may not accurately represent actual flows.

Calibration and Verification

The model was calibrated and verified against field data that were collected from January to June of 1999. Then the model was applied to scenarios that were proposed by the study team. Three series of model simulations were requested. The first simulation included flows from the Northwest Fork of the River and its three tributaries based on flow ratios established by a

previous study. The second simulation contained a minimum amount of freshwater input from the three tributaries. The first simulation method was used to predict salinity conditions with various freshwater inflow rates that follow historic freshwater input patterns. Details regarding the basic model setup, data sources and assumptions and calibration/verification process and preliminary model results for these simulations are presented in detail in **Appendix E** of this report. A third simulation was performed, in order to develop a 30-year salinity data set, as described in the following section:

Simulation of a 30-Year Salinity Record for the NW Fork

The next step in the development of minimum flow criteria for the Northwest Fork of the Loxahatchee River was to develop a relationship between the river vegetation database and historical changes in salinity over time. Since long-term, continuous salinity records (e.g., 30-years of data) were not available for the river at each vegetation sampling site location, a method was developed to generate a time series of historical salinity data (1971-2001) at each of the seven river vegetation sampling site locations **(Table 17)**. This was accomplished through the use of an RMA-2/RMA-4 hydrodynamic/salinity model (USACE 1996) and a computer program developed in house. The computer program, described in **Appendix E** as a *long-term salinity model*, uses the RMA-2/RMA-4 model output and the freshwater flow at Lainhart Dam to provide an estimate of daily average salinity at eight sites in the upper Northwest Fork.

The input for th long-term salinity model application was the 30 years of flow data (1971-2001) obtained from USGS and SFWMD flow records for the Lainhart Dam. Additional flow data from other tributaries were located and processed (see **Table 15**), but were not used in this analysis. Analysis of the additional historical data indicated that these data were in close agreement with the initial estimates of flow from the three tributaries. Model output consisted of a 30-year simulated time series of mean daily salinity values (1971-2001) plotted for each vegetation sampling site, which are provided in **Appendix H**. **Table 16** provides the location of each river vegetation survey site where long-term salinity records were developed using the hydrodynamic/salinity model. From these data SFWMD staff plotted individual time series, and calculated descriptive statistics (mean, standard deviation, median, mode and maximum daily salinity concentrations) for each site for the 30-year period of record.

A "salinity event analysis" was also conducted to group the simulated salinity data from each site into salinity events that equaled or exceeded a particular salinity threshold. For each threshold of salinity concentration at 1 ppt intervals (e.g. 1 ppt, 2 ppt, 3ppt, etc.) The amount of time in days that this concentration was continuously exceeded (Ds) was determined, as well as the number of days that elapsed from one event to the next (Db). Salinity conditions at a site were expressed in terms of Ds and Db for a minimum threshold value as a means to express the degree of exposure to salinity that might be experienced by the vegetation community at that location. As expected, the duration of a salinity event decreases, and time between salinity events increases, as one moves from downstream to upstream sites.

Table 17. Sites along the NW Fork of the Loxahatchee River where long-term salinity records were simulated using the hydrodynamic/salinity model.

Site Name	Sample Type		Site Location*
	Vegetation	Water Quality	
Site 7-C and WQ #64	X	X	River Mile 7.8
Site 8-B	X		River Mile 8.4
Site V-6 and WQ #65	X	X	River Mile 8.6
Site 8-D (8-st)	X		River Mile 8.9
Site 9-B	X		River Mile 9.2
Site WQ #66		X	River Mile 9.4
Site 9-C	X		River Mile 9.7
Site 10-B	X		River Mile 10.2

* River miles upstream from the Jupiter inlet; see also **Figure 16** and **Table 16** for the location of these sites along the NW Fork of the river.

In terms of potential effects of salinity exposure (or any toxic substance) on freshwater vegetation, the magnitude (concentration) and duration of exposure to elevated salinity levels is related to the extent of damage to the freshwater community caused by that exposure (see Pezeshki et al. 1986, 1987, 1990, 1995; Conner and Askew 1992; Allen 1994; Allen et al. 1994, 1997). The time between salinity events is also important to allow sufficient recovery from the last damaging salinity event. Other analyses included calculation of the percent of time that salinity was equal to or above a particular salinity threshold value (e.g., 1 ppt, 2 ppt, 3 ppt, etc.). Results of these analyses are discussed in **Chapter 5** of this report.

Documentation of Historic Water Use within the Loxahatchee Basin

SFWMD Consumptive Use permitting records were examined to identify those permits that were located within the Loxahatchee River watershed and determine their current water usage. In this study, public water supply, landscape irrigation and agricultural water demands within the basin were estimated based on: (a) the annual allocation of each permit holder obtained from District records and (b) the average daily demand values used in the Northern Palm Beach County Comprehensive Water Management Plan hydrologic model (MODFLOW). Permitted withdrawals by use category for 1999 were summarized. Permitted allocation values were also compared to actual pumpage values submitted to the District by the permit holder to get a comparison of the amount of water actually used during normal operations and what is used during peak demand periods. Unfortunately, many of the data records were missing or incomplete. Results of this analysis are presented in **Appendix O.** Data from these permits were also used as input to the interactive surface-water groundwater model (see below).

Simulation of Consumptive Uses within the Loxahatchee Basin

The overall effect of consumptive uses (public water supply, agriculture and self-supplied residential wells) on the ability to provide flows to the Northwest Fork was considered as part of the MFL process. Use of the surficial aquifer and river for public water supply is a resource

function. Several approaches were used to estimate the proportion that consumptive uses within the basin comprise of the watershed's hydrologic budget.

To address this issue, District staff analyzed available hydrogeologic data and conducted a number of groundwater model simulations. Data were obtained from SFWMD and USGS databases. Model scenarios were run using a modified USGS three-dimensional finite difference flow code (MODFLOW-96) model that was developed by the SFWMD for northern Palm Beach County (SFWMD 2002). This model provided a means to determine relative effects of consumptive uses within the basin on water levels in Loxahatchee Slough and deliveries to the Northwest Fork of Loxahatchee River during selected wet, normal and dry periods. Results of this analysis are presented in **Appendix I.**

Biological Methods

Literature Review

Pursuant to Section 373.042(1), F.S., the District is required to utilize best available information to establish the MFL. In this regard the District performed an intensive review of the existing literature to (1) identify the water resource functions of the river and estuary that need protection, and (2) to determine the technical relationships among flow, salinity, and river hydrodynamics that impact key indicator communities, or species present within the NW Fork of the river. Specifically, the review involved: (a) identifying individual species or biological communities that could serve as useful indicators, targets, or criteria for determining a minimum flow for the NW Fork and the estuary; (b) determining how these indicator species or indicator communities have been impacted by structural and/or hydrologic alterations of the river and upstream watershed; (c) reviewing the previous experiences of the SFWMD and other water management districts with respect to the establishment of MFLs for surface water bodies; and (d) evaluating the Valued Ecosystem Component (VEC) approach to establish a MFL for a tidal river. The following is a summary of the information that was reviewed and evaluated for development of the MFL for the Loxahatchee River/Estuary system.

The library card catalogs of the SFWMD, University of Miami (UM) and Florida Atlantic University were reviewed for relevant citations. In addition, Internet searches were performed using open-access general searches and search engines. Individual key words and combinations of key words were searched to cover: Loxahatchee River, cypress, mangroves, seagrasses, vegetation, macro-invertebrates, benthic fauna, submerged aquatic vegetation, forested freshwater wetlands, tidal river, estuary, hydrology, freshwater flow, minimum flows, salinity tolerance, salt intrusion, ground water, soil salinity, and sea level rise.

A literature review was conducted utilizing the *Bibliography on Water Resources in the Loxahatchee River Watershed* (Dent 1997a). Information was also obtained through dialogue

with the Loxahatchee River Environmental Control District, Jonathan Dickinson State Park, and the UM Department of Biology.

An additional literature review was conducted to identify the: 1) key species or groups of organisms that may benefit from utilizing cypress swamp and/or cypress riverine wetland communities of the Northwest Fork; 2) life history of bald cypress; 3) salinity tolerance of bald cypress, cabbage palm, laurel oak, Virginia willow, dahoon holly, pop ash, pond apple, red bay, red maple and red mangrove and 4) acute and chronic responses of bald cypress seedlings and adults to salinity 5) historic wetland vegetation changes on the NW Fork and 6) estimates of sea level rise in South Florida. **Appendix A** provides a bibliography of all the documents reviewed by staff as part of the literature review.

Aerial Photography/GIS Studies

District staff utilized existing historical aerial photography to compare spatial and temporal changes in the distribution and abundance of vegetation communities along the floodplain of the Northwest Fork of the Loxahatchee River. Black and white aerial photographs taken in 1940, 1953, and 1964, were compared to color infrared photographs taken in 1979, 1985 and 1995 to quantify changes in the distribution and abundance of freshwater hardwood and cypress communities and mangrove communities between river miles 6.6 and 8.9. The 1940 aerial black and white photographs were obtained from the National Archives (College Park, Md.) while the 1953, 1964, and 1979 photographs were obtained from the U.S. Department of Agriculture, Consolidated Farms Service Agency in Salt Lake City, Utah. The 1985 color infrared photographs were obtained from a special flight conducted for the SFWMD over Lake Okeechobee and portions of the Loxahatchee River Watershed, and the 1995 photographs were Digital Ortho Quads (DOQs) obtained from the National Aerial Photography Program.

The percentages of freshwater hardwood community, cypress, mangrove, cabbage palm, ornamental species, and disturbed or cleared lands were calculated for the 1940, 1985 and 1995 aerial photographs to quantify the extent of vegetation cover change through time. The 1940 and 1995 aerial coverages were further divided into six river segments (Lower NW, Mid-NW, Upper NW, Wilson Creek, Kitching Creek, and Island Way Creek) to delineate the locations on the river and tributaries where these changes have occurred. The 1995 photo interpretations were also partially ground-truthed, based on data obtained from a recent vegetation survey conducted along the River by District staff (see following section).

The category of *cypress* represents a community that is dominated by cypress (more than 50% coverage), but also includes red maple, pond apple, pop ash, water hickory, laurel oaks, sweet gum and bays. The category of *stream swamp* represents a freshwater community that is primarily comprised of mixed hardwoods in which cypress is present but not dominant. Cabbage palms, which can occur in both swamp and upland communities, may occupy areas along the Northwest Fork that are tidally flooded or occasionally flooded.

District staff also visited and re-examined three sites along the Northwest Fork one along Kitching Creek that were originally documented by Alexander and Crook (1975) during their investigation of long-term changes in South Florida vegetation communities. The purpose of this work was to document changes in vegetative cover and correlate those to major events or alterations within the watershed. **Appendix B** provides a detailed summary of methods utilized in the aerial photography and field investigations.

River Vegetation Surveys

Semi-Quantitative Vegetation Survey (November 2000/December 2001)

A semi-quantitative vegetation survey method, suitable for statistical analyses, was conducted by SFWMD biologists to examine community-wide changes along the NW Fork of the Loxahatchee River and Kitching Creek. Sixteen sites (labeled 5B through 10C) were selected and surveyed in November 2000 and seven additional verification sites (labeled V1 through V7) were surveyed in December 2001 (**Figure 16**).
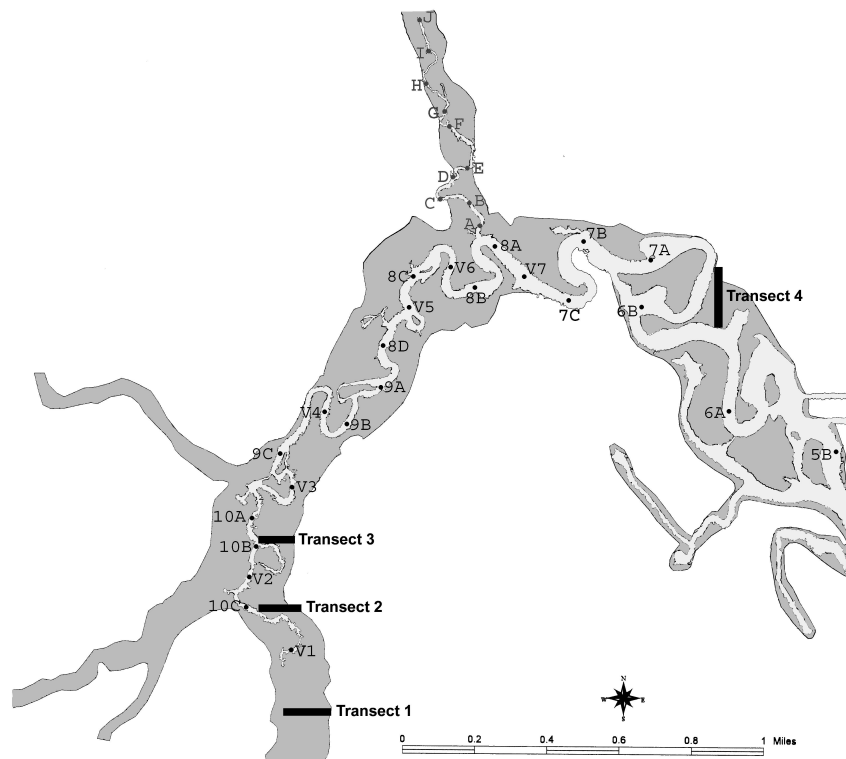

Figure 16. Locations of Vegetation Survey Sites along the Northwest Fork of the Loxahatchee River and Kitching Creek. Semi-quantitative sites (23) were sampled in November 2000 and December 2001. Quantitative Sites (V1, V3, V7, 8B, 8D, 9A, 9B, 9C) were sampled again in January 2002. Transects 1-4 indicate sites where preliminary soil-salinity samples were collected.

Locations of these sites were not random, but rather based upon the following criteria:

- Survey sites were located more than 100 feet from a river bend or oxbow to reduce the potential effects of shifting currents, riverbank dynamics, and river flow energy on vegetation community composition.

- Survey sites were located at or near the center of the River's floodplain and at least 100 feet away from the floodplain-upland transitional zone to reduce the possible influence of freshwater seeps on vegetation community composition.

- The survey examined vegetation within an area approximately 400 feet. (122 m) long by 50 feet. (7.5 m) wide along each river bank, at a site.

- All vascular plant (macrophyte) species present and an estimated abundance index for each species were recorded.

The abundance index was determined from a dichotomous key that categorized a species' abundance or cover into four classes. This method follows a modified version of the Braun-Blanquet cover-abundance scale (Braun-Blanquet 1932, 1965; also see Mueller-Dombois & Ellenberg 1974, Bonham 1989) and was conducted as shown in **Table 18.**

The semi-quantitative survey investigated general vegetation trends along the River that may be associated with different salinity conditions, and identified "key" species of interest, which were sampled in greater detail in the quantitative vegetation survey. **Appendix C** of this report provides more detailed information on the methods and results of the semi-quantitative vegetation survey.

Table 18. Dichotomous Key that was Used as the Basis for Detemining the Abundance Index

Description of Species Population Density	Abundance Index
1a. Species not present…………………………………………………….……….……0	
1b. Species present.	
2a. Two or less individuals; rare...………………………………….……….……….……1	
2b. More than two individuals.	
3a. Highly abundant or dense population (>75% cover), a dominant component of the plant community…………………………………….….…..…4	
3b. Species not a dominant component of the plant community	
4a. Sparse; widespread and of low density or restricted to localized populations……………………………………….…..…….…2	
4b. Common; widespread and of moderate density but not a dominant component of the plant community (<50% cover)………….……….………..…3	

Quantitative Vegetation Survey (January 2002)

SFWMD biologists conducted a quantitative vegetation survey along the NW Fork of the Loxahatchee River in January 2002. Nine of the sites previously surveyed by the semi-

quantitative method (see previous section) were re-surveyed. Six of these sites (8B, 8D, 9A, 9B, 9C, and 10B) were used to compare against previously collected semi-quantitative data while the remaining three sites (V1, V3, and V7) (see **Figure 16**) were used as verification for the SAVELOX model, which will be discussed in a later section.

At each sampling site, two strip quadrats (belt transects) were established, one along each opposite shoreline. Each strip quadrat was 200 ft (60m) by 25 ft (7.5m), covering an area of 5000 ft^2 (465 m^2). The selected area of each strip quadrat was larger than that typically used to estimate density in tree communities (see Bonham 1989). At each of the nine sites, the parameters listed in **Table 29** were measured and recorded for different age classes of the "key" species identified in the semi-quantitative vegetation survey and literature review as having varying degrees of salinity tolerance. Age classes were defined as adults (mature), saplings (juvenile taller than breast height), seedlings (shorter than breast height), and stump sprouts (damaged adults that were resprouting from a trunk).

Table 19. Measured Parameters* for Key Species.

Recorded Parameter	Adults	Saplings	Seedlings	Stump Sprouts
Number of Individuals	X	X	X	X
Mean Canopy Diameter (used to calculate tree cover)	X	X		X
Tree Height	X	X		X
Trunk Circumference (used to calculate DBH**)	X	X		X (cumulative)

*a discussion of the methods and importance of these parameters in forest studies can be found in Mueller-Dombois & Ellenberg 1974, Bonham 1989

**DBH= trunk diameter at breast height

Tree height was estimated using the hypsometer method (Boy Scouts of America 1967; Bonham 1989) while mean tree canopy diameter (length measurements of the shortest and longest branches) and trunk circumference at breast height were measured with a tape measure. Tree cover area was calculated using the following equation: Cover = [(canopy diameter/2)^2]p. The cumulative tree canopy cover for tree height classes was used to examine vertical distribution of the canopy cover and its changes associated with salinity conditions. Tree diameter at breast height (DBH) was calculated using the following equation: DBH = (tree circumference at breast height)/p.

Soil Salinity Survey

District staff conducted soil sampling along the Northwest Fork in January 2002 to investigate soil salinity concentration changes along the river and to serve as a reconnaissance effort to gain information upon which to base future sampling projects. Four transects were established across the river floodplain, at sites representing different degrees of salinity exposure from tidal flux, and extended from the riverbank to the edge of the upland-floodplain ecotone (**Figure 16**).

Within each transect, four 10 m^2 plots were established at varying distances from the river channel to examine soil salinity concentration changes relative to the river. Grab samples were collected from the upper one-foot of soil in the plots established in Transects 1, 2, and 3 while a soil corer was used to collect soils from depths of 0-0.33 m, 0.33-0.67 m,, and 0.67-1.0 m increments in the plots established in Transect 4. Transect 4 was sampled more intensively, since this was the site that appeared to be most impacted. Sufficient amounts of soil were collected from all of the plots to provide enough water for conductivity and chloride analysis. The water samples were extracted at the Loxahatchee River Environmental Control District's laboratory and analyzed for conductivity according to the Standard Methods section 2510B and chlorides by an argentometric titration method, as described in Standard Methods (Franson 1998). Conversion tables were used to convert the conductivity and chloride results to salinity values, which were then entered into a spreadsheet and analyzed for trends associated with vegetation and estimated long-term (30-year) salinity conditions at each site. **Appendix G** provides additional information on the soil survey.

Estimate of Historic (Pre-Development) Flow Conditions for the Watershed

During the course of this analysis, questions were raised concerning the amount of water that "naturally" flowed from this watershed prior to development. Although this was an interesting question from a historical and perhaps a restoration perspective, it was deemed to be not particularly relevant in light of the extensive changes that have occurred in the watershed and adjacent waters during the past century. Results of this analysis are provided in **Appendix N**.

Statistical Analyses of Relationships between River Flow and Salinity

A number of approaches were used to develop relationships between flow from Lainhart Dam and salinity conditions at various locations in the River. Results of these analyses are described in **Appendix D.** Comparison of these results with the output from the hydrodynamic salinity model (discussed above) indicated that the model produced comparable results to those obtained from the statistical relationships. However, use of the model was deemed preferable due to the interactive qualities of the model and the fact that it could be used to predict conditions over a larger portion of the river and estuary.

Development of a River Vegetation/Salinity (SAVELOX) Model

Using the vegetation survey results and the salinity time series generated from the hydrodynamic salinity model, correlation analyses were used to examine vegetation trends relative to salinity event duration from specific sites along the river corridor. From these data a river vegetation/salinity model (SAVELOX) was developed using an empirical approach to extrapolate vegetation parameter response given a set of long-term salinity conditions. Where highly correlated relationships ($r^2 > 0.90$) were found between measured vegetation parameters and estimated long-term salinity conditions, formulas were developed to describe these relationships, and a deterministic regression model was constructed to predict (extrapolate)

vegetation community response to salinity. The model formulas were based upon the correlation between measured vegetation parameters (i.e. abundance, height of adults, canopy cover, etc.) and a calculated salinity ratio Ds/Db (defined below) at those sites where both computed salinity and vegetation survey data existed.

The mean duration of each salinity event (*Ds*) and the mean number of days between events (*Db*) at each site, as derived from the 30-year salinity simulation (see section earlier in this chapter entitled, *Simulation of a 30-Year Salinity Record for the NW Fork*), were combined to create a ratio (*Ds/Db*) that provided a quantitative expression of the degree of exposure to salt water that occurred at each location along the river. Event duration and time between events can be expressed in any time scale (days, weeks, months), however in our application we used *days* as the standard unit of measure for calculation of this ratio. A *Ds/Db* ratio of 1 indicates that half of the time average daily salinity at a site are at, or above, a selected salinity threshold. *Ds/Db* ratio values greater than 1 indicate a predominance of saltwater conditions. In contrast, the ratio decreases rapidly as one travels up river from the central embayment area and approaches zero as constant freshwater conditions are observed **(Figure 17).** For this reason, the *Ds/Db* ratio was used as a general index of salinity at a given location along the River and was a key relationship used to develop the river vegetation salinity model.
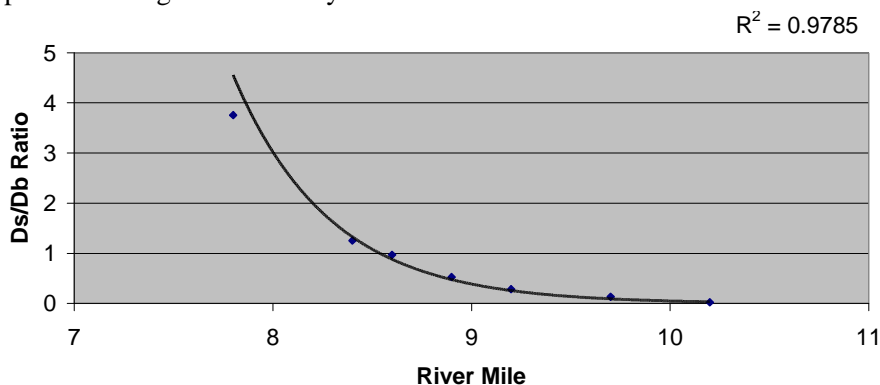

Figure 17. Relationship between the ratio of the amount of time that a station at a particular river mile along the Loxahatchee River was exposed to salinities above 2ppt (*Ds*) and the amount of time that elapsed between exposure events (*Db*) as a function of distance upstream from Jupiter Inlet

Usually, the model formulas were linear regression models with one independent variable and of the form:

$$f(x) = bx + e, \quad \lim_{x \to c} = g \quad \text{and} \quad \lim_{x \to d} = h$$

where e is the expected error, x is the independent or regressor variable, and *b* is the expected change in $f(x)$ per unit change of x (see Montgomery 1997). The function has an upper limit of *g* as x approaches the real number *c*, and a lower limit of *h* as x approaches the real number *d*.

The model was developed in a MS Excel workbook and linked to a user input spreadsheet. User input of a salinity event duration (Ds) and duration of time between events (Db) at a specified salinity threshold (e.g. 2 ppt) is used to calculate a predicted vegetation parameter value, which is displayed in numeric and graphical formats. Verification of these relationships and their ability to accurately predict intermediate values were conducted by comparing predicted values with those from verification sites that were not used in formula development**.** Vegetation parameters calculated by the model are shown in **Table 20**. **Table 21** shows the sites used to derive model formulas and the sites used for model verification.

Table 20. Vegetation Parameters Included in the Salinity-Vegetation Model

Vegetation Parameter	Model Output
Abundance of a species	Species name and estimated abundance index[1]
Number of Adults per site	Estimated number of adults of each "key" species
Canopy cover (percent area of site)	Estimated canopy cover of adults as percent of total surveyed area

[1]see Methods section entitled "Semi-quantitative Vegetation Survey" **Appendix C**

Table 21. Loxahatchee River Sites Used to Derive Model Formulas

Site Name (River Mile)	Data Types			Application		
	Semi-Quantitative Vegetation Data	Quantitative Vegetation Data	Estimated Salinity*	Vegetation Trends	Salinity-Vegetation Relationships	Model Verification
Site 5-B (RM 5.6)	X			X		
Site 6-A (RM 6.2)	X			X		
Site 6-B (RM 6.8)	X			X		
Site 7-A (RM 7.3)	X			X		
Site 7-B (RM 7.5)	X			X		
Site 7-C (RM 7.75) WQ Station 64	X	X	X	X	X	
Site V-7 (RM 8.0)	X	X				X
Site 8-A (RM 8.1)	X			X		
Site 8-B (RM 8.4)	X			X	X	
Site V-6 (RM 8.6) WQ Station #65	X		X			X
Site 8-C (RM 8.7)	X			X		
Site V-5 (RM 8.8)	X					X
Site 8-D (RM 8.9)	X	X		X	X	
Site 9-A (RM 9.1)	X	X		X		
Site 9-B (RM 9.2)	X	X	X	X	X	
Site V-4 (RM 9.35) WQ Station 66	X		X			X
Site 9-C (RM 9.7)	X	X	X	X	X	
Site V-3 (RM 9.9)	X	X				X
Site 10-A (RM 10.1)	X			X		
Site 10-B (RM 10.2)	X	X	X	X	X	
Site V-2 (RM 10.3)	X					X
Site 10-C (RM 10.4)	X			X		
Site V-1 (RM 10.5)	X	X	X			X

*see **Appendix E**,